Cryogenic thermal design overview of the 30 K passively cooled integrated science instrument module (ISIM) for NASA's Next Generation Space Telescope

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ABSTRACT

Baseline configurations for NASA's Next Generation Space Telescope (NGST) include a multi-module science instrument package with near-infrared (near-IR) detectors passively cooled to below 30 K. This integrated science instrument model (ISIM) will also house mid-infrared (mid-IR) detectors that are cooled to 6-7 K with a mechanical cooler or stored cryogen. These complex cooling requirements, combined with the NGST concept of a large deployed aperture optical telescope passively cooled to below 40 K, makes NGST one of the most unique and thermally challenging missions flown to date. This paper describes the current status and baseline thermal/cryogenic systems design and analysis approach for the ISIM. The extreme thermal challenges facing the ISIM are presented along with supporting heat maps and analysis results.

Key words: cryogenic, thermal, sunshield, NGST, passive cooling, radiator, ISIM, heat map

1. INTRODUCTION

Currently in phase A development and scheduled for launch in 2010, NASA's NGST is expected to replace the Hubble Space Telescope as the premier space based astronomical observatory. With a six to eight meter primary aperture, deployed actively-controlled cryogenic optics, and an instrument suite of near-IR and mid-IR cameras and spectrometers, NGST is expected to observe the very early universe, one million to a few billion years old, when the first stars and galaxies began to form. NGST will be diffraction limited at 2µm, with approximately a 0.1 arc–second resolution, and have nano–Jansky sensitivity[1].

A large deployable sunshield enables the observatory to take advantage of the low temperature sink provided by space. The ISIM utilizes a very large two-stage radiator system to achieve 30 K passively on the near-IR instruments' sixty-four mega-pixels of combined detectors. The extremely cold ISIM environment also affords the opportunity to conduct mid-IR observations and also enables the use of stored cryogens for cooling the mid-IR camera's detector for up to ten years without adversely impacting NGST's total mass.

After nearly a half decade of study and analysis, passive cooling of the near-IR detectors has been shown to be feasible and is now a primary requirement[2] of any potential NGST architecture. As NGST proceeds now into a detailed design phase and architectural possibilities are narrowed to one, this paper presents the current status of the baselined ISIM thermal design, alternative configurations, and remaining issues to be addressed.

2. OBSERVATORY THERMAL CONFIGURATION

2.1 Mission level requirements related to thermal control

NGST is to be Zodiacal background limited over a wavelength range of 0.7 to ≥ 10 µm, thus requiring NGST's telescope and instrument optics to be cooled to less than 50 K. There are currently two types of instrument detectors being developed for the near-IR instruments, indium antimony (InSb) and mercury cadmium telluride (HgCdTe). The currently understood operating temperature requirement is 30 K for the InSb and 37-45 K for HgCdTe. Since the final

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detector selection will not occur until 2003, all potential NGST and ISIM designs must be compatible with passive detector cooling to 30 K. This is the dominant requirement related to ISIM thermal control. Obviously, with higher temperature detectors the passive cooling challenges are somewhat relaxed. However, other thermal considerations related to NGST's mid-IR instrument (MIRI), (e.g. stray light emissions from the ISIM optics) could potentially drive the ISIM thermal design. Alternative configurations addressing these scenarios are presented later in this paper.

Detectors suitable for operation at ≥ 10 μm will require cooling to < 7 K. Passive cooling is not practical at 7 K, thus a stored cryogen system, with an operational lifetime of ten years[3], is currently baselined. State-of-the-art mechanical cryocoolers, currently under development[4], could also be used and the system compatibility and architectural impacts of such systems have been studied. Regardless of cryogenic cooler system finally chosen, the ISIM must minimize parasitic heat inputs to the MIRI to levels compatible with cryogen lifetime and anticipated cooler capability.

2.2 Mission orbit selection

Based on extensive study, NASA has selected the Sun-Earth Lagrange point, or L2, as the required location for NGST[5]. The L2 point is located 1.5 million km from the Earth in the direction opposite the Sun. NGST will orbit around the L2 point in a large halo orbit. L2 is advantageous from a passive cooling perspective as Earth heating is negligible and the telescope and instruments can be shaded from the sun while simultaneously allowing for a large view of the sky and continuous illumination of the spacecraft's solar arrays. NASA's Microwave Anisotropy Probe (MAP), launched in 2001, has successfully used the advantages of L2 to passively cool its payload below 90 K.

2.3 Architectural options

From 1996 thru 1998 a NASA government team developed a NGST study architecture and mission design referred to as the 'yardstick.'[6] This yardstick design was used to steer technology development, verify feasibility of the NGST concept, and to serve as a baseline or reference design with which to further study design issues and resource budgets. Figure 1 illustrates the yardstick configuration and approximate scale of key observatory elements. The most prominent feature is the large deployable sunshield. This sunshield shades the ISIM and optical telescope and provides the first stage of passive cooling[7]. The ISIM is deployed, along with the telescope, away from the warmer (293 K) spacecraft bus via a conductively isolating boom or truss.

Via a competitive down-select procurement, NASA is currently choosing NGST's final architecture and primary vendor. Although the architectures, shown in Figure 2, are significantly more evolved than NASA's 'yardstick', fundamental architectural features have not changed.

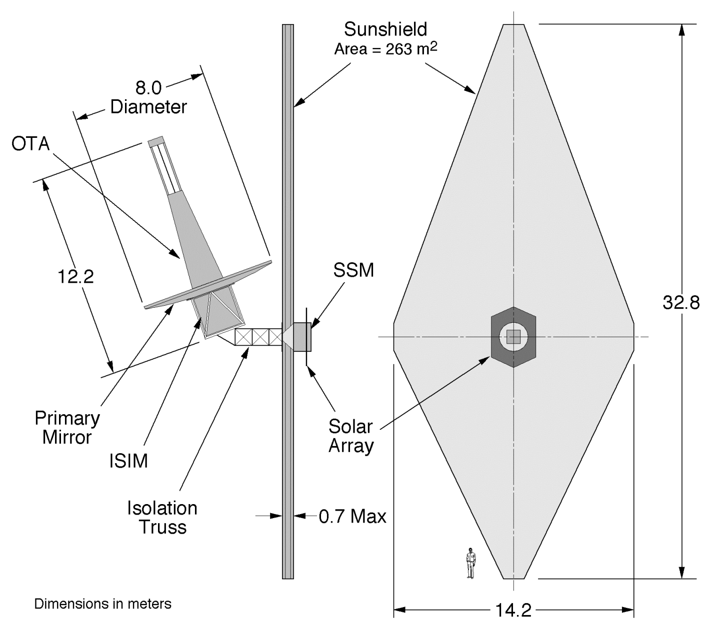

Fig. 1: General layout of NASA yardstick concept.

3. ISIM THERMAL CONFIGURATION

3.1 ISIM overview

The ISIM is essentially a support module for the individual science instruments. The ISIM will provide common services, i.e. pick off optics, structural support, instrument cooling, electrical power and command and data handling. The philosophy is that the individual instruments will 'plug into' the ISIM and, to the maximum extent, utilize a set of standardized

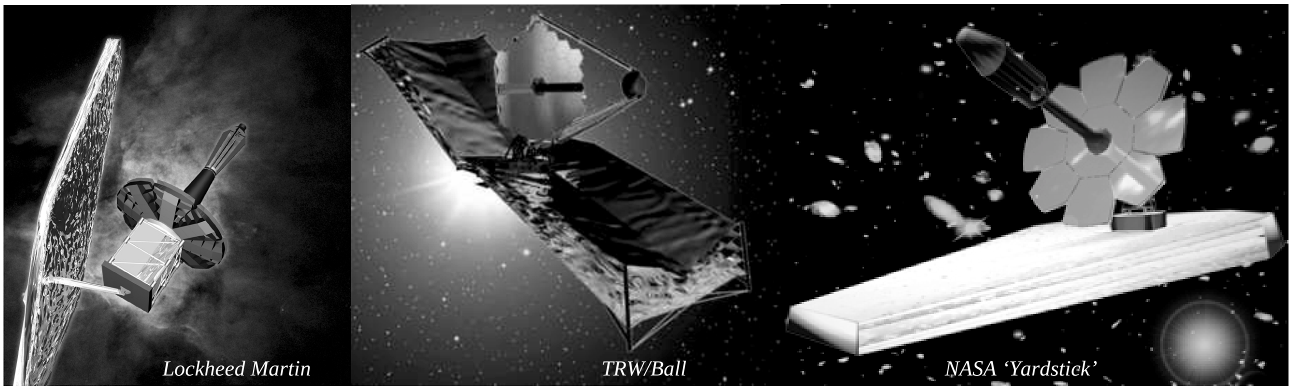

Fig. 2: NGST architecture concepts. *Images courtesy of Lockheed Martin, TRW, and NASA.*

interfaces. Figure 3 illustrates the ISIM concept. The core of the ISIM consists of an optical bench structure that is mounted to the telescope. Individual instruments mount to this optical bench via kinematic mounts. A set of large radiators and enclosures surround the instruments and optical bench structure. High-powered and room temperature electronics that support the ISIM are located on the spacecraft bus. The entire ISIM, including scientific instruments has a mass of 1000 to 1500 kg.

Since the final ISIM configuration is highly dependent on the chosen NGST architecture, details of the ISIM and scientific instruments design are pending. These design details and issues involving them can only be addressed once there is a single NGST architecture.

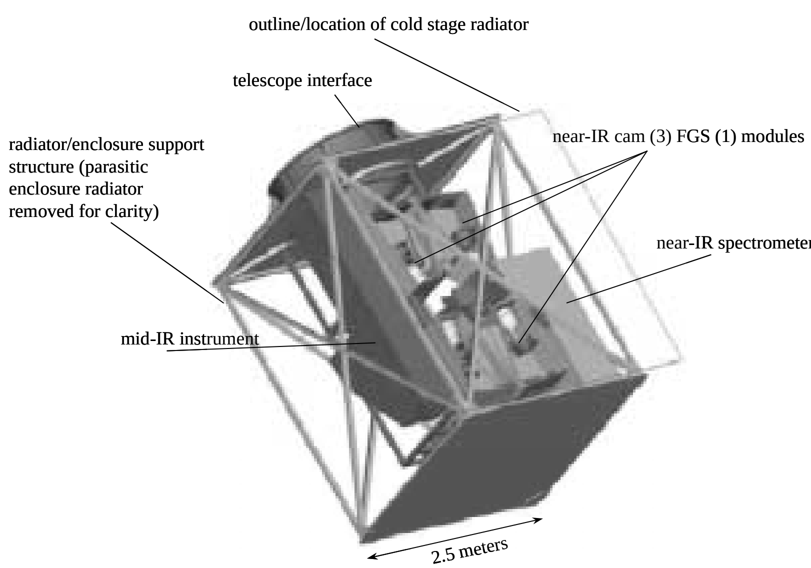

Fig 3: NASA 'yardstick' ISIM concept.

3.2 Thermal design approach

Since passive cooling to 30 K is a fundamental architectural and system level design driver for the NGST observatory, cooling of the instrument detectors is provided by the ISIM. The ISIM thermal design accommodates all instruments as if they were a single unit. This is critical for successful cooling to 30 K as an instrument's individual thermal response and dissipation could potentially impact the other instruments. Figure 4 shows a block diagram for the baseline ISIM thermal concept. ISIM power dissipation is directed in two different directions. Mechanism heat, due to filter wheels, flip mirrors, focus, etc., is conducted away via the instrument mounts into the ISIM optical bench structure, nominally at 35 K. The heat is either then transferred to the telescope or to the ISIM enclosure radiator via radiation or supplemental heat straps. Heat dissipated on the detectors is directed to the large cold stage radiator, nominally at 28 K. Yardstick thermal studies of the ISIM sized this large radiator at eight square meters. Conductive and radiative isolation of the detector assemblies minimizes parasitic heat input from the rest of the ISIM. The cold stage radiator is also conductively isolated from the rest of the ISIM.

Near-IR camera. The near-IR camera is the primary NGST instrument and consists of three separate modules to provide the required large field-of-view. Each module has a 4k by 4k, 16 mega-pixel, detector assembly that is mounted to, but thermally isolated from, the near-IR-camera optical bench and housing. Three lightweight thermal straps, one for each module, connect the detectors to the cold stage radiator. Mechanisms are hard mounted to the near-IR camera structure allowing for heat dissipation to the ISIM optical bench structure.

Near-IR spectrometer. Like the near-IR camera, the spectrometer is highly coupled to the ISIM optical structure and its single 4k by 4 K detector is thermally strapped to the cold stage radiator.

Fine guidance sensor. The fine guidance sensor, or FGS, provides guide star positioning information to the observatory's attitude control system during science observations. Although not an instrument, the FGS in mounted within the ISIM and must be thermally controlled via the ISIM radiator system. Regardless of what detectors are used within the FGS, they can be highly thermally isolated and allowed to run warmer than the ISIM. The FGS will be conductively coupled to the ISIM optical structure via its kinematic mounts.

MIRI. Because of its unique low temperature requirement and low overall dissipation, the MIRI is highly isolated from the rest of the ISIM to minimize parasitic heat loads on its cryogen. The baseline MIRI concept utilizes a dual stage solid hydrogen-solid neon dewar thermally coupled to a 6 K detector assembly and an 18 K aft optics bench. Fore-optics and the bulk of the MIRI structure are not controlled but are nominally at 30 K. The MIRI instrument is a joint NASA-European Space Agency (ESA) collaboration. ESA is currently revisiting the cryostat design and investigating cryogen and cryogen sizing options utilizing the latest MIRI to ISIM interface information.

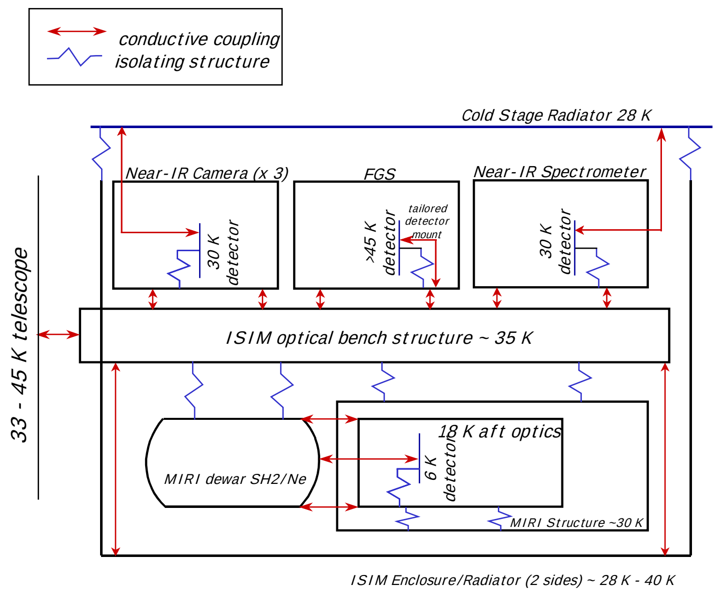

Fig. 4: ISIM baseline thermal control concept

One of the primary issues facing the ISIM is that of the telescope temperature. Because the telescope is also passively cooled, the ISIM thermal design must also be able to accept heat from the telescope and dissipate it on the enclosure radiator. The ISIM optical bench structure, nominally kept at 35 K is mounted to the telescope, whose temperature ranges between 29-45 K.

4. ISIM THERMAL ANALYSES

4.1 Modeling approach

The success of passive cooling to 30 K relies heavily on the quality of the thermal modeling. Thermal modeling is critical in insuring that the heat loads within the ISIM are compatible with radiator and dewar sizes and with the required operating temperatures. Cryogenic thermal models need to be highly detailed such that all heat paths are accounted for. Modeling software needs to access temperature dependent material and optical property databases that span NGST's wide range of temperatures. Complicating the ISIM thermal modeling effort is the large number of organizations involved in the ISIM project. While NASA's Goddard Space Flight Center (GSFC) bears overall responsibility for the ISIM thermal design and analysis, a successful design depends on the contributions and modeling efforts of NGST's prime contractor and the multitude of organizations that will provide the individual scientific instruments and other ISIM hardware. Within the ISIM there is high thermal interaction among the various ISIM components and externally the ISIM interacts to a high degree with the rest of the NGST observatory. These subtle but important thermal interactions must be accounted for in all of the NGST thermal models. The usefulness of classic interface control documentation to manage thermal interfaces among the various parties involved is diminished due to the vagueness and sensitivity of the interfaces. Because of this, the ISIM and NGST thermal teams will continually review all ISIM and NGST thermal models to insure that assumptions and results are within the bounds of the agreed to interfaces and within the capabilities of the radiators and cryogen volumes.

Figure 5 depicts the flow and make up of the various thermal models. The GSFC will construct ISIM system level models consisting of key ISIM assemblies, e.g. electrical harness, the optical bench, enclosure/radiator system, heat straps, etc. To this model GSFC integrates reduced or simplified versions of the instrument models created by the individual instrument providers. The NGST observatory level thermal models created by NGST's prime contractor provide ISIM to observatory thermal interfaces and boundary conditions. The ISIM model is then used to verify and update all ISIM interfaces. The ISIM model or a simplified version of the ISIM model is integrated with the observatory system model and system level architecture requirements are verified and ISIM to observatory interfaces are refined. Detailed heat maps of the entire observatory and ISIM are created and reviewed on a quarterly basis. This continuous exchange of models and subsequent refinement of the heat exchange is essential to the ISIM and NGST design process to insure that 30 K can be achieved passively.

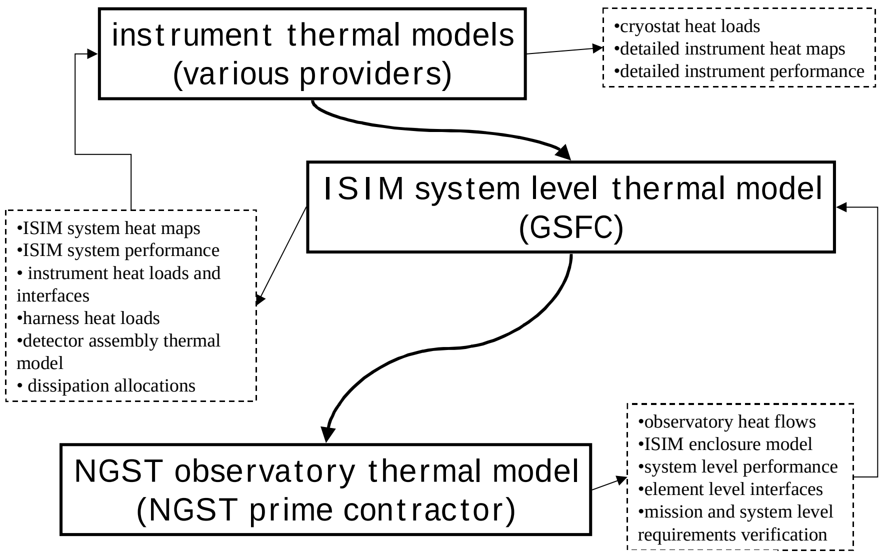

Fig.5: NGST thermal model integration and output products.

4.2 Modeling tools

The ISIM thermal modeling effort needs to account for the growing variety of thermal analysis software tools available to the international thermal analysis community. ISIM system thermal models will be constructed in either Systems Improved Numerical Differencing Analyzer (SINDA) or TMG formats and geometric radiation modeling will be performed in either TMG or the Thermal Synthesis System (TSS). Input models, e.g. instrument provided models, not in these native formats will be translated and thoroughly verified for proper operation prior to insertion into the host model. Likewise, the ISIM system level model will be translated to the NGST prime's contractor's preferred format and thoroughly verified prior to integration into the NGST system model.

4.3 Heat load budgets

Table 1 contains a baseline summary of the heat dissipation and harness parasitic allocations within the ISIM. Strict control and monitoring of these allocations is also critical for passive cooling success. The majority of the heat load is attributed to the one milli-watt per mega-pixel currently allocated to the detector assemblies. The detectors account for approximately 53 % of the total cold stage load. While it is estimated that the detector dissipations are conservatively high, the high percentage of detector-generated heat actually helps to build confidence in the capability of the passive cooling system. Detector dissipations can ultimately be measured in the lab environment where as parasitics are based purely on analysis until thermal balance testing. Even after testing the parasitics carry an amount of uncertainty. Typically, radiatively cooled cryogenic systems are dominated by parasitics. The cold environment provided by NGST's sunshield minimizes parasitics and allows detector dissipation to dominate the total cold stage load. It is this unique ratio of dissipation to parasitics that build confidence in the ISIM thermal design and leads to a unique thermal margin approach that is subsequently addressed. The MIRI loads shown are only approximate and are better reflected in on-going MIRI studies.

		dissipation (milli-watts)
near-IR camera		
	detector dissipation	50
	stability heaters	21
	mechanisms	19
	harness load (allocation)	37
near-IR spectrometer		
	detector	17
	stability heaters	6
	mechanisms	44
	harness load	13
FGS	detector	17
	stability heaters	14
	mechanisms	18
	harness	13
MIRI	detector dissipation	3.2
	mechanisms	8
	harness load	11.5
total ISIM dissipation		***291.7***
total cold stage (30 K)		***144***

Table 1: Representative heat dissipation allocations.

4.4 Material and thermo-optical properties

A variety of material systems are currently being investigated by GSFC for the ISIM main optical bench structure and radiators. Of particular importance is the ISIM's dimensional stability over temperature. Thermo-elastic stability of the ISIM needs to be compatible with the nanometer level tolerances of the optical system. Carbon composites, beryllium and associated alloys, silicon-carbide, and even aluminum are being considered. Baseline GSFC ISIM studies assumed a structure of AlBeMet, an aluminum beryllium alloy, with aluminum instruments and radiators.

The most critical thermo-optical property is the effective emittance of the radiators at 30 K. A preliminary minimum emittance requirement is currently 0.7. GSFC has initiated calorimetric emittance testing at 30 K of several coating/material combinations to identify candidates that meet the emittance requirement.

4.5 Cryogenic design margin philosophy

NGST's passive cooling requirement presents a unique set of circumstances when considering cryogenic design margin. Since the 30 K temperature is a strict system level requirement, margin is tracked and quantified via the cold stage heat loads and not its predicted temperature. The issue then is how much heat load margin should be maintained over the various stages of the program. One approach, based on a study of several cryogenic missions, recommends a 50% heat load margin prior to the critical design review and 25% after system verification and prior to launch[8]. In other words, the heat loads could increase by 50% and the cooling system could still maintain the required temperature.

Because there is no space flight heritage with passive cooling to 30 K, the NGST thermal team originally opted for 100% total heat load margin on the cold stage radiator system. This quickly became a difficult architectural design hurdle as the radiators, sometimes larger than eight square meters, must be packaged within the constraints of the launch vehicle faring. Early heat maps of the system also illustrated that the ISIM's ratio of power dissipation to parasitic heat was much larger than that of typical cryogenic systems. This ratio of measurable and somewhat controlled heat to much more unpredictable parasitic heat lead to the decision to adopt a 50% total heat load margin as a system level requirement[9]. This allowed ISIM designs to proceed given the packaging and volume constraints of the architectures. Although not an architectural requirement, the ISIM thermal team has chosen to track parasitic heat load separately from total heat load. Given that parasitic heat load represents the more uncertain and greatest challenge to manage, it is intended to keep at least 100% margin on the parasitics. In other words, given that dissipation is controlled and constant for any given design analysis, parasitics could grow by 100% and the 30 K temperature requirement would still be met.

Total heat load margin and parasitic heat load margin will be tracked and reviewed quarterly as part of the quarterly heat load and thermal interface audit.

4.6 Heat map and margin analysis

Figure 6 shows an example of an NGST ISIM top-level heat map from one of the earlier government yardstick ISIM thermal studies used to verify the 30 K passive concept. Although different from the current architecturally dependent

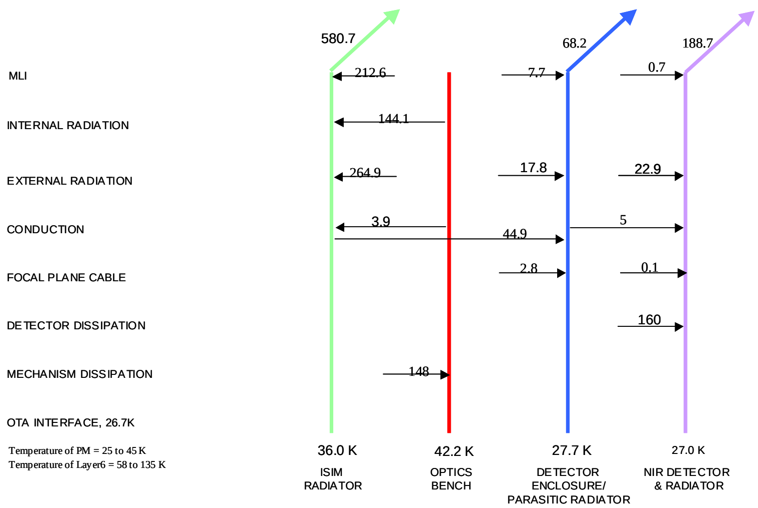

Fig. 6: ISIM high level heat map from 'yardstick' study**.**

maps, it does illustrate in the global sense the heat paths and loads for the basic ISIM passive cooling concept. For this particular analytical design cycle, there were three radiators. These early heat maps led to the decision to combine the detector enclosure and detector radiators, yielding the current two-radiator system. Applying the aforementioned margin assessment with the eight square meters cold stage radiator this particular design iteration was showing 52 % total heat load margin and 345 % total parasitic margin.

5. ALTERNATE THERMAL CONFIGURATIONS

5.1 Mechanical cooler options

Early studies of the mid-IR instrument options for NGST examined the use of the next generation of cryo-coolers currently under development. NGST places unique demands on these mechanical systems. The cooler would have to be segmented such that the cold head could be remotely positioned within the instrument while the warmer high heat-dissipating compressor is located on the spacecraft bus such that its heat does not impact the cryogenic side of the observatory. In the case of the yardstick architecture, cooling lines to the cold head would have to have considerable length, greater than five meters, and capable of deployment along with the telescope and ISIM. NGST image stability would require the cooler's components meet strict vibration requirements. Also, the dual temperatures, 6 K and 18 K, of the baseline MIRI instrument would require multiple stages. These challenging requirements for coolers not yet in existence led the NGST project to baseline stored cryogens as the baseline MIRI cooling technique. Because NGST is to be the first of many cryogenic space-based telescopes, NASA has begun the Advanced Cryo-cooler Technology Development Program (ACTDP), in order to better serve the cooling needs of these future missions. Since NGST could potentially benefit from the use of these advanced coolers, options for their use must still be kept open. One possible configuration utilizes a mid-stage radiator to increase cooler efficiency. The radiator, at approximately one square meter and at less than 100 K, could easily be accommodated in the variety of NGST architectures.

5.2 37-45 K HgCdTe near-IR detection option

As previously mentioned, higher temperature detector technology could be chosen for the near-IR instrument detectors. While the ISIM and NGST architecture are required to passively cool to 30 K, Figure 7 illustrates a conceptual change in the design if HgCdTe technology is used. Since MIRI still requires cold ISIM optics and has stringent stray light requirements the bulk of the ISIM would still be kept at approximately 40 K. The baseline cold-stage radiator would be segmented and approximately half would be coupled to the ISIM optical bench in order to dissipate the rerouted detector heat. The rest of the radiator would be well thermally strapped to the MIRI housings in order to intercept the added parasitics from the optical bench. The near-IR detector assemblies would be allowed to run at 45 K via a conductively tailored mount. In such a scenario, the MIRI instrument would predominately drive the thermal design of the ISIM and cryogenic passive cooling margin would increase significantly.

5.3 Near-IR optimized option

If for some reason, NGST becomes a near-IR mission only, the ISIM thermal design concept would change even more dramatically. The optimal approach for an NGST optimized for near-IR observation, would have a 90 K telescope with

HgCdTe detectors passively cooled to 45 K. The overall warmer temperature of the telescope and ISIM would greatly ease thermal verification and thermal vacuum testing. Since heat loads from the telescope would be much larger than in the current baseline, an additional parasitic radiator would have to be added to the current two-radiator system to intercept the higher loads from the telescope.

6. DETAILED ELECTRICAL HARNESS THERMAL MODELING

6.1 Harness impact

Heat flow via electrical harnessing is always an issue for any cryogenic system. Unbeknownst to the engineering teams studying NGST, the design of the electrical harness connecting the large near-IR detector arrays to the room temperature analog to digital and control electronics would become one of NGST's toughest architectural challenges. As design details began to develop for the detector electronics and associated harnessing it became apparent that heat flow via the harness could overwhelm the capacity of the 30 K cold stage radiator. In addition to thermal concerns, electrical issues related to transmitting sixty-four million pixels of high quality detector signals over the several meters of payload to spacecraft bus separation further complicates the issue. In addition to opposing electrical and thermal requirements, manufacturing and reliability had to also be addressed. To illustrate the problem the heat flow based on the electronics to detector delta temperature of 270 K, a single 32 AWG copper wire and a six-meter length, has been calculated at 0.9 milli-watts. This in itself is not a large number. However, baselined harness designs require approximately 2100 of these wires resulting in a total cold stage heat flow of 1.9 watts. Since this number is clearly incompatible with the available radiator sizes, the NGST thermal and electrical teams collaboratively analyzed hundreds of possible harness configurations to identify a solution for both the data transport requirements and the 50 mW allocation for harness heat loads.

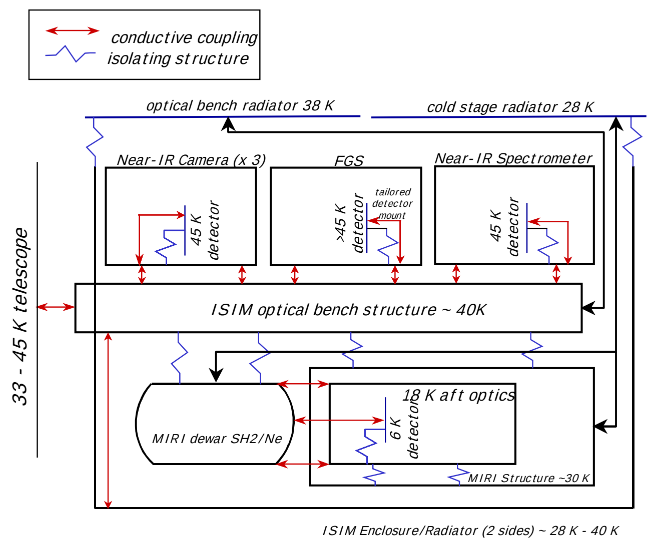

Fig. 7: Cooling concept if near-IR detectors cooled to 45 K.

6.2 Design variables

Based on timing and capacitance requirements flowed down from high level detector read out rates and data quality requirements, electrical studies concluded that any harness system could be no longer than approximately six meters without signal amplification, resulting in increased power on the detectors. Therefore, reducing heat flow by elongating the harness was not an option. The approximate number of wires, including shields and redundancy, was also changing throughout the study, and ranged from 2000 to 3000. For reliability and simplicity reasons, options for segmenting the harness and or using thermal breaks, e.g. silicon bridge chips, were not considered. This left only flexibility in the choice of material and gage for the wire and associated shielding.

6.3 Thermal model description.

Because the temperature drop profile of the harness is not linear and the potential harness materials have dramatic changes in thermal conductivity over temperature, a highly detailed thermal model with over 6000 elements was created in TMG. The model included 600 divisions along its length and included the effects of insulation and containment materials. Earlier harness analyses even included radial heat transfer and external harness radiation, but for conservatism, and concern over the accuracy of the modeling, subsequent efforts excluded radiative cooling.

6.4 Baseline harness design

Figure 8 shows the history of the calculated harness loads as various materials and harness configurations were studied. Latest analyses estimate the harness load at approximately forty milli-watts, ten milli-watts below the allocation. Since digitation of the detector signal could be done at the detectors, via an application specific integrated circuit (ASIC) mounted directly to the detector, an alternative harness accommodating its unique electrical needs had to be configured and analyzed. Table 2 presents the current harness configurations for both the ASIC and non-ASIC electrical configurations. Throughout the study a variety of low thermal conductivity wire materials, including copper, phosphor bronze, copper-nickel, aluminum, manganin, constantan, and stainless steel were evaluated for their electrical and thermal compatibility. Small gage stainless steel has been chosen for the baseline harness and phosphor-bronze for the ASIC version. Stainless Steel actually was the preferred material for the ASIC design to meet the electrical resistance requirement of 7.2 Ω/meter. However, when available wire gages were taken into account, phosphor-bronze was the superior choice.

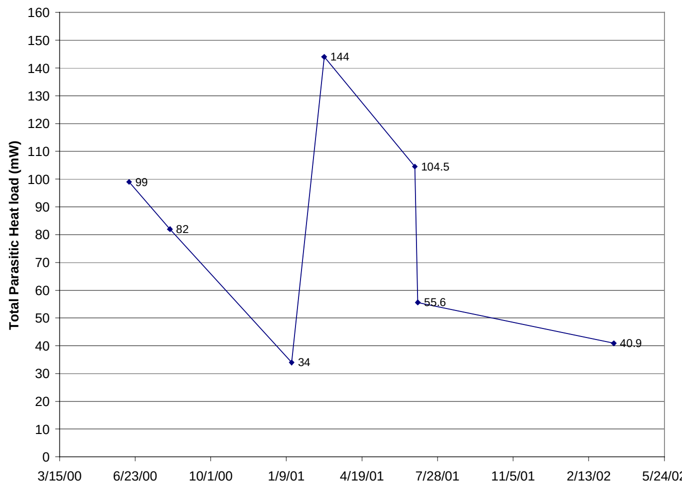

Fig. 8: Calculated harness heat load variation.

Analog Science Harness

24 Ribbon Cables
40 Wires per Ribbon Cable
38 AWG Wire
- Stainless Steel 304
- 70/30 Copper-Nickel cladding, 0.00254mm (for soldering)

Dual Copper Shield (2500Å copper)

Analog Mechanism Harness

32 Ribbon Cables
40 Wires per Ribbon Cable
34 AWG
- Stainless Steel 304
- 70/30 Copper-Nickel cladding, 0.00254mm (for soldering)

Single Copper Shield (2500Å copper)

ASIC Science Harness

Per ASIC:
15 Stainless Steel 304, 34 AWG (Chassis ground, synch, command, status)
3 pairs of LVDS (Clock, Data)
- 34 AWG, Phosphor-Bronze
- 40 AWG, Stainless-steel braid

Dual Copper Shield (2500Å copper)

Table 2: Harness design summary - circa May 2002.

7. DESIGN ISSUES AND RISKS

Although the ISIM thermal system has been extensively studied, many issues and risks remain regarding the details of the design. These issues and design details are currently being assessed and will be need to be resolved early during the preliminary design phase after the NGST architecture is selected.

Cold-stage radiator design. The thermal performance or effective emittance of the 30 K radiator represents the single largest risk to ISIM's passive cooling approach. Figure 9 illustrates the dramatic impact on margin that even a slight deviation in radiator emittance would have. In addition to the current effort to quantify the emittance at 30 K of potential coating/material systems, extensive prototyping and thermal testing will be conducted early in the next design phase to verify the radiator design's overall thermal performance. This development testing will occur on much smaller versions of the actual flight radiator. In addition to thermal performance, these small scale prototypes will serve as pathfinders to verify manufacturing and coatings application techniques. Thermal strap interface design and characterization will also be carried out on these prototypes.

Thermal strap design. Specifications for the detector assembly to cold stage radiator thermal straps are currently being created. Candidate strap materials and designs that meet these specifications will then undergo a rigorous developmental test program to finalize the strap design. Material candidates include copper, aluminum, and high conductivity composites. Current models allow for a 0.5 K temperature drop through the strap. In addition to effective conductivity the strap development program will also examine issues related to strap mass, strap stiffness and structural support, and the ability to reliably attach the straps to the radiator and detector systems with consistent interface conductance values.

Heat switches. Although not currently baselined, the use of mechanical and gas-gap heat switches is being considered to address several interesting issues. During launch and early orbit, heat switches could be used to disconnect the radiator from the detectors in order to minimize the risk of overheating them due to anomalous attitudes and sun exposure on the high performance radiators. Heat switches could also be used to bypass the MIRI isolation system in order to help speed up the cool down of the MIRI structure and dewar. Finally the use of heat switches may be needed during thermal testing. Cooling down the massive ISIM only with radiation would take an impractical amount of time. Heat switches connecting the ISIM to mechanical coolers or helium cold plates could be engaged to facilitate cool down and disengaged to allow for on-orbit like thermal balance conditions. The use of heat switches could potentially benefit these specific areas of concern.

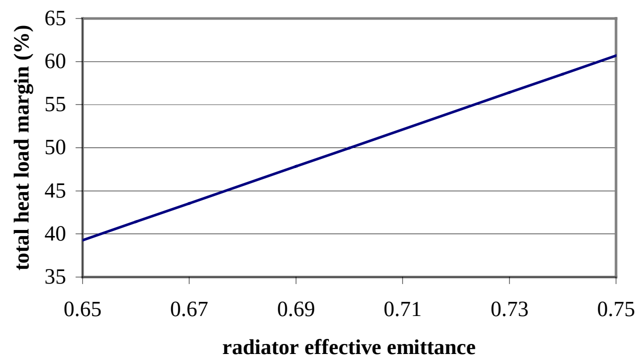

Fig. 9: Radiator performance impact.

Dissipation growth. After radiator performance, dissipation or power growth within the ISIM represents the next largest risk to the ISIM's passive cooling system. Dissipation growth that would result in a violation of the previously discussed margin requirements would require an increase in radiator size, a potentially large system impact to the architecture, or limited science operations of the instruments. Heat loads, specifically dissipation must be carefully monitored for growth and quickly assessed for their impact on the required margins.

Thermal verification. While passive cooling to 30 K is feasible in the quiet and cold thermal environment of L2, it will be very difficult to do in a test chamber situation. Even with helium refrigerator systems cooling the chamber shrouds, heat leaks from the test setup equipment, chamber reflections, etc., will create a much more difficult thermal environment than on-orbit. Extensive thermal analysis of candidate test setups is currently being conducted to examine the potential to reach operational temperatures. Supplemental cooling could be used to further pull down the ISIM temperatures or the ISIM could be allowed to cool as much as possible. If the latter option is chosen extensive model correlation to the resulting temperature would be needed to verify the ISIM's cooling performance. These correlated models would then be used to re-assess the on-orbit performance. If supplemental cooling is used to reach operational temperatures then the amount of additional cooling would need to be accurately quantified in order to correlate the model.

8. SUMMARY

Current thermal design concepts for the ISIM are compatible with all of the mission and system level cooling requirements for both the near-IR and mid-IR instruments. The ISIM concept is ready to proceed to the preliminary design phase, and developmental design and testing of candidate thermal hardware can begin. Extensive study and thermal analysis of the ISIM has refined thermal interfaces such that detailed studies of the instruments and cryostat could commence. Conceptually, the ISIM thermal design is flexible enough to accommodate the variety of programmatic and technical changes likely to impact a program such as NGST. Finally, because NGST is a corner stone in NASA's space science enterprise, and a pathfinder for even larger and colder space based telescopes, it is the intent of the authors to periodically update the interested science and engineering communities on the continuing development and design of the ISIM's novel and unprecedented passive cooling approach.

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